INEEL/CON-02-00141
PREPRINT

Idaho National Engineering
and Environmental Laboratory

Developing Automated Methods of Waste Sorting

R. M. Shurtliff

August 4, 2002 – August 8, 2002

Spectrum 2002

Developing Automated Methods of Waste Sorting

Rodney M. Shurtliff

Idaho National Engineering and Environmental Laboratory

2525 Fremont Avenue

Idaho Falls, Idaho 83415-2220

rshurtli@inel.gov

ABSTRACT

The U.S. Department of Energy (DOE) analyzed the need complex-wide for remote and automated technologies as they relate to the treatment and disposal of mixed wastes. This analysis revealed that several DOE sites need the capability to open drums containing waste, visually inspect and sort the contents, and finally repackage the contents into containers that are acceptable at a waste disposal facility such as the Waste Isolation Pilot Plant (WIPP) in New Mexico.

Conditioning contaminated waste so that it is compatible with the WIPP criteria for storage is an arduous task whether the waste is contact handled (waste having radioactivity levels below 200 mrem/hr) or remote handled. Currently, WIPP non-compliant items are removed from the waste stream manually, at a rate of about one 55-gallon drum per day. Issues relating to contamination-based health hazards as well as repetitive motion health hazards are steering industry towards a more user-friendly, method of conditioning or sorting waste.

Under the direction and funding of the Department of Energy Mixed and Transuranic Waste Focus Area, a method of moving the operator further away from the hazards of sorting mixed waste is being developed. It is referred to as the HANDSS-55 (Handling and Segregating System for 55-gallon Drums). The HANDSS-55 consists of four basic modules, one of which is the Waste Sorting Module. Within the sorting module are components that provide the means for an operator to sit in a remote control room and sort waste using a touch screen display, a joystick and cameras.

The sorting module is the heart of the HANDSS-55 (See Figure 1) and includes many unique features which include, 1) a 3-D imaging system; 2) a high speed positioning system; 3) a sorting table that tilts and vibrates; 4) a telescoping "Z" mast (a vertical motion axis); 5) a variety of tools or end-effectors; 6) a sophisticated control system based on leading edge software technologies; and 7) a bag opener tool.

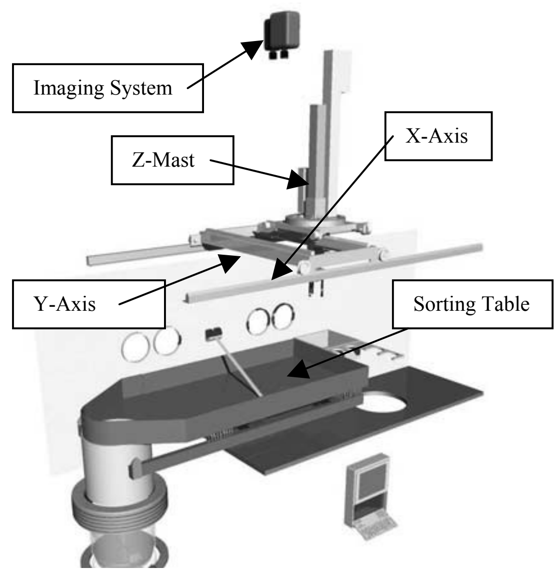

Figure 1—Sorting Station

Integrating all of these components together so that they physically fit together is challenging. Creating a control system that controls all of them simultaneously and allows interaction, while preventing collision and interference is even more challenging. Couple all of this with designing the equipment for operation and maintenance in a containment cell and the task becomes monumental.

I. INTRODUCTION

The requirements for the HANDSS-55 were developed with input from the Savannah River Site in South Carolina since they will be the recipients of the final system. The contact handled waste application at Savannah River Site is to provide a test bed for the new technology in an environment that will be less restrictive than a remote handled waste application. An important aspect of the system is the requirement for the robotic system to work directly with human operators. This introduces safety issues and time delay issues (no one likes to wait long for a system to respond to a command). A design that would provide accuracy, speed, safe interaction with human operators and reliability was developed and implemented as the HANDSS-55 Sorting Station.

As good as a system may be, it is well known that Murphy is alive and well. Fall back capabilities were necessary to design into the system to assure that an operator could continue to process even the difficult waste streams. Three modes of operation are defined for the Sorting Station: 1)Automated; 2) Tele-operative; and 3) Manual.

Developing a deployment system for a robotic grasper that is robust, fast and easily maintained in a glovebox environment is challenging. It must have a range that covers the length of the glovebox and be capable of lifting several hundred pounds.

Opening waste bags was found to be difficult. Each bag is different and contains objects that might be flammable or contain liquid containers that must not be broken. A safe solution was found that requires little maintenance, but does require operator interaction.

The 3-D imaging system was developed in conjunction with VX Optronics[i]. The measurement system provides a profile of waste that is located ten feet below on a stainless steel table. Combining distance information with color and edge detection data, objects are identified to the operator.

The challenge associated with automated waste sorting is that of an unstructured environment. Typically, robots used in industry have the luxury of knowing what they are to pickup and where it is located. With a wire-frame reference as a guide, robotic systems can be programmed to identify automatically objects in space to be picked up. The challenge in automated sorting of waste is to pick up unknown objects with no reference for comparison.

Following the removal of non-compliant objects from the waste stream, the remaining objects left on the sorting table may be dumped into the load-out port. The tilt table has a vibrator attached that allows the waste to be moved slowly into the load-out port to prevent clogging the opening to the waste container.

The end-effectors or tools used on the end of the Z-mast are critical to performing the sorting function. A universal grasper, a suction cup, an electro-magnet and an alignment tool make up the collection of end-effectors currently available. Working with Barrett Technologies[ii] an industrial version of the BarrettHand is being developed which will better meet the needs of HANDSS-55.

II. THE CHALLENGES

A. XY Deployment System

The requirements for an X/Y deployment system for operation inside of a containment cell are centered around maintainability and reliability. Commercially available systems are constructed of extruded aluminum framework which are difficult to decontaminate. Most are enclosed with some type of covering to hide the drive mechanism. This again makes it difficult to decontaminate unless it is an airtight seal—none are. For ranges of travel greater than ten feet, the typical approach is to use a poly belt or chain of one design or another which in turn requires the use of pulleys and/or sprockets to operate. Although the life expectancy is good on these products, the belts and/or chains must be replaced eventually and present a very difficult decontamination problem.

B. Z-mast "Reach" or Stroke

Accessing waste objects found on the sorting table does not require a long Z-mast stroke. Should an object inadvertently be placed or fall into the load-out port or off of the sorting table, a long reach would be needed to retrieve the object. A telescoping Z-mast is not an off-the-shelf item—especially one designed for glovebox operation.

C. Object Definition Speeds

When interacting with a human operator, the speed of the process becomes very important. Extended periods of inactivity during a process are not desirable. When creating a profile of an object on the sorting table, the larger the region of interest around the object, the longer it takes to process that data. If a high degree of resolution is required to do the task, the processing time is extended. Tradeoffs are necessary to obtain the needed resolution while minimizing the processing times.

D. Defining Adjacent and Overlapping Objects

When waste is dumped onto the sorting table, it is quite certain that some objects will be obscured or partially obscured by other objects. If non-compliant objects are to be removed from the waste there must be a capability of moving objects from one place to another on the table (in order to uncover objects of interest) and the ability to identify objects that are closely adjacent to each other and overlapping.

E. Opening Waste Bags

The contaminated waste stored in 55-gallon drums was packaged in plastic bags and closed using a "J-wrap" technique. This is a simple method of folding over the top of the bag and wrapping it with duct tape. It is not uncommon for each bag to be double and triple bagged, that is, the waste has been put into two or three separate bags. Opening these six to eight-mil thick bags automatically is extremely difficult. A variety of methods have been tried with varying results.

F. Clearing the Table

In a Visual Examination mode of sorting (at least 3% of all drums going to WIPP must be visually examined per WIPP criteria), each object of waste must picked up, weighed and visually and verbally described. If only the non-compliant items are to be sorted from the waste, the rest of the waste may be repackaged without inventorying each object. Reliably removing all objects from the table without jamming the opening to the load-out or repackaging port requires a method of "sifting" or moving the objects in a controlled manner to the load-out port.

G. End-effectors/Tools

In industrial robot applications the items to be moved by the robot are known. Typically they are of one size and shape allowing the use of a specially designed parallel gripper or jaw with minimal stroke to be used to pick up the object. When sorting waste, the objects vary from plastic shoe covers to hammers making it difficult to use one end-effector to pick up all objects. On the other hand, it is desirable to minimize the number of end-effector changes for obvious reasons of time delay and wear and tear on tool plate connectors. Use of an end-effector that can pick up a high percentage of all of the waste objects is needed.

III. THE SOLUTIONS

The requirements for a glovebox contained automated sorting station are rigorous. Materials, surface finish, maintainability, reliability are all important factors in the design of the system. These requirements alone dictated the direction of many engineering decisions. Understanding these restrictions, the following solutions were achieved for the previously mentioned Sorting Station design challenges.

A. XY Deployment System

A stainless steel bridge and trolley system was designed that could be positioned using ac induction linear servo motors. Magnetically coupled encoders in conjunction with the servo motors allowed positioning of the axes to within +/- 1-mm of a designated position. The motor system required only four moving parts for each axis—four sealed bearing wheels riding on stainless steel rails. The length of travel is unlimited and the motors drive the bridge and trolley as fast as one would dare move that much mass. The speed limitation is mostly due to the objects being moved—it is not desirable to launch an object from the end-effector from stopping too fast. The motor mounts have been designed such that the motors can be removed and replaced through glove ports located in the containment glovebox. End-of-travel switches, a home switch for position initialization, and pneumatically operated brakes are also included in the design of the system.

B. Z-Mast Stroke

A telescoping Z-mast was designed to provide a stroke of 88-inches necessary to reach into the load-out port and retrieve items that may have inadvertently been placed or fallen into it. The design of the telescoping sections uses anodized aluminum to minimize the weight. The bottom section of the four section mast can be removed in-cell to allow replacement of a rotary motor, a force/torque cell or the intelligent end-effector control module. The control module provides flexibility in interfacing to a variety of different end-effectors without requiring a change in cabling. All cabling is contained within the telescoping stages to prevent snagging or breaking a connector or cable. A custom coiled cable was designed to fit around a locking chain. The chain is manufactured by Serapid[iii] and provides a push and pull capability to the Z-mast. It is capable of speeds up to 40-ft/minute.

The rotary motor is a through-hole, direct drive motor with no gears. Located inside of the third telescoping stage, it provides accurate, 340-degree rotation. Continuous rotation was avoided to eliminate the need for a slip ring wire feed to the intelligent module. Optical sensors are located inside the mast to indicate forward and reverse end-of-travel for the R-axis.

C. Defining Overlapping and Adjacent Objects

At the heart of the automated sorting function is the ability to identify objects to the extent necessary to deploy an end-effector to pick it up and remove it from the waste stream. Utilizing a stereo measurement system (VX Optronics' StarCam—see Figure 2) and structured lighting, X, Y and Z coordinates are measured for each white dot projected onto the sorting table waste. A color image of the waste is captured and using these arrays of color, Z information and standard edge detection techniques, objects are identified from the profiles found on the sorting table. The objects are outlined on an operator screen to indicate to an operator the objects that have been identified. An operator then has the option of modifying the outline or accepting the outline as accurate. When the outline is accepted by the operator, the robotic system is directed by the control software to pick the object from the waste using end-effectors selected by the operator. This provides an automated method of sorting the waste with interaction from the operator, but without requiring difficult or even strenuous activity on the part of the operator.

Figure 2. StarCam Stereo Measurement System.

Objects that may be partially obscured or so close to similar or identical objects that the measurement system cannot distinguish between them can still be picked up by operator intervention. The operator can either move the end-effector pick-up points indicated on the display or he can modify the outline of the object to reflect the actual perimeter of the object to be picked up. Either option is much faster and easier than attempting to remove the object using tele-operative control via joystick of the robotic system. This option is available to the operator as an option.

IV. Opening the Waste Bag

Another difficult operation of the Sorting Station is to open the bags of waste. Each bag may be several bags thick making it difficult to identify what is inside. The following techniques were investigated with varying degrees of success:

A. Hot knife—this technique was messy and required constant cleaning of the knife blade. The burning plastic was a concern, although the off-gasses would be captured in the hepa filters within the glovebox. Automating the opening of the bag was not successful because of the irregularity of the shape of the bag; great gaps occurred in the cutting as the bag was rotated by the Z-mast.

B. Rotating cutters mounted in portable cutting tool—several types of cutting wheels were used. In each case, the irregularity of the bag made it difficult to cut cleanly through the bag. The biggest concern was if liquid filled containers were contacted within the bag, the possibility of cutting through them and spilling the liquid was high. Dulling the blade by hitting metal objects was also a problem.

C. Laser—the laser cutting system worked extremely well. The bottom of the bag could be cut reliably clear through at a fairly rapid rate. The problem was flammability. If paper or other flammables were in the path of the laser, they would likely be ignited. A nitrogen purge prevented ignition while the combustible was in the bag, but when it was exposed to the air (which would happen when the object would fall from the bag) it would sometimes ignite. The safety issues to be solved did not make it worth pursuing engineering solutions for these problems.

D. Hot air gun—Similar problems experienced with the laser cutting precluded the use of a hot air gun for opening the bags. The temperature required to melt the plastic clear through was hot enough to begin to burn paper products. Again, the irregular shape of the bag made it difficult to completely cut through the bag as the bag was rotated.

E. Cutting shears—modified pruning shears were found to be the most effective means of opening the bags. This method does not lend itself well to automated opening of the bags, unless cutting the top of the bag is desired. In that case, it can be automated. The difficulty in using this method is that the bag is open, but still full of waste. The most effective method was found to be opening the bottom of the bag in a tele-operative mode. This allowed gravity to help empty the bag and maintain the empty bag in the gripper. The empty bag can then be disposed of which helps keep the table open for waste sorting. Liquid filled containers are not likely to be perforated using the shears—they are used like scissors to cut along one side of the bag.. There is no danger of flammability and if done carefully, most of cutting done is of the plastic bag, which does not dull the cutting blades rapidly.

The shear was found to be the most effective and safest method of opening the waste bags. If maintenance on the shear is necessary, it can be removed from the Waste Cut Bag Opener by a manual tool plate connection. This requires access through a glove port.

F. Clearing the Table

The method of clearing the table allows an operator to sift the contents of the table into the load-out port at the end of the table. The table can be tilted through a range of –2-degrees to +28-degrees. It was found that tilting alone was not sufficient to move the waste into the load-out port. Oftentimes, the waste would not slide off at all, even at its maximum tilt range, until a small amount of vibration was initiated. This would then break the surface tension of the waste items and they would slide into the load-out port. With practice, it was found that tilt angles and vibration levels could be used together to provide a sifting process which moved the waste items into the load-out port without jamming or plugging the hole.

G. End-effectors/Tools

Many institutions and companies are involved in the development graspers to emulate grasp of a human hand. Several have been successful in some aspects and have developed prototypes. Only one company has developed a truly commercial grasper that has universal pickup capability. Barrett Technologies has sold over fifty models of its BarrettHand to industry and universities. While not mimicking the human grasp, it provides two fingers of the three finger grasper that can be moved from 0 to 180-degrees and provide a programmable grasping method. This light duty grasper has features that are needed in HANDSS-55, but it is not designed for contaminated glovebox operation. A cooperative development project is currently underway to build a second version of the BarrettHand which will provide a robust grasper capable of operating in a process, glovebox environment. It will provide a grasping capability that will allow a high percentage of the waste to be sorted without changing end-effectors.

Figure 3. BarrettHand Three Finger Grasper

V. CONCLUSION

Developing an automated sorting station for glovebox operation has been challenging. Many engineering challenges have been encountered in the design of the system. Each challenge has been addressed and good engineering solutions have been achieved. The functionality of the system will provide a capability never before used and will increase productivity and throughput for the waste sorting activity at Savannah River Site and throughout the Department of Energy complex. Applying this same technology to remote handled waste is planned soon.

The future will include fully automated sorting techniques as systems are developed which can be taught to recognize non-compliant items and remove them from the waste stream. The system developed at the INEEL provides the basis for this next step into the future.

---

[i] Vx Optronics is now known as Vx Technologies Inc. They are located in Suite 2000, 777-8th Avenue. S.W., Calgary, Alberta, Canada T2P 3R5, Tel: 403) 233-2236

[ii] Barrett Technologies, President & CEO: William Townsend, 139 Main St., Kendall Square, Cambridge, Massachusetts, 02142-1528, USA, 617-252-9000.

[iii] SERAPID U.S.A. Inc., 6600 Sims Rd, Detroit/Sterling Heights, MI 48 313, USA, tel : 1 586 274 07 74
fax: 1 586 274 07 75